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METHODOLOGY FOR LOGISTICS ANALYSIS DURING CONCEPTUAL DESIGN

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This paper documents a methodology for performing logistics analysis of a weapon system during the conceptual design phase. The methodology is a systems analysis approach and includes examples from a referenced analysis effort. An outline of methodological considerations is provided for future efforts. Keywords

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DURING CONCEPTUAL DESIGN

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SUMMARY

Decisions affecting 85% of the life-cycle cost of a weapon system program are made before full-scale engineering development begins. The Air Force currently lacks an adequate methodology to analyze supportability issues during the conceptual design phase. At the request of the Air Force Systems Command, Aeronautical Systems Division (ASD), Wright-Patterson AFB, Ohio, the Air Force Human Resources Laboratory (AFHRL) accomplished a program to demonstrate the feasibility of analysis of the logistics drivers and impacts of future gunships during conceptual design. This paper documents this methodology.

The major steps in performing this systems analysis are: (a) scoping the problem; (b) developing the scenario; (c) acquiring the data; (d) performing the modeling; and (e) interpreting the results. The description of this approach is highlighted with specific examples from the analysis. An outline of methodological considerations (Appendix B) has been developed for use by others contemplating such logistics analysis. It is hoped that further use will refine and extend this methodology to a point where logistics analyses will be routinely performed during conceptual weapon system design.

PREFACE

This paper documents a methodology for performing logistics analysis during early phases of weapon system design. It is one of six reports resulting from an Air Force Human Resources Laboratory, Logistics and Human Factors Division (AFHRL/LR) program to develop and demonstrate methodologies to perform front-end logistics and human factors analyses on a weapon system design in the conceptual design phase. Two of these reports have been published. AFHRL-TR-86-21, Sustained firepower study: Logistics requirements for deployment of an improved AC-130 gunship, is a preliminary estimation of selected logistics resources required to support deployment of 10 near-term replacement gunships. AFHRL-TR-86-58, Logistics composite model analysis of a future gunship design, documents the results and methodology used to quantify the sortie generation capability and maintenance manpower requirements for a hypothetical, state-of-the-art gunship. Future reports to be published will present:

1. results of human factors and training analyses of future gunships;

2. methodology for front-end human factors analyses;

3. executive summary of AFHRL/LR research efforts in analyzing conceptual weapon system designs.

The Laboratory has applied the knowledge gained from this research and development effort to ASD's Replacement Gunship Program and the Gunship III effort. Currently, we are supporting the Advanced Tactical Fighter program office with a very similar effort called the Small Unit Maintenance Manpower Analyses (SUMMA) project. An in-house Laboratory research effort is currently in the planning stage for developing methodologies for evaluating manpower, personnel, and training (MPT) issues in the design phase. This research also directly supports the Air Force Systems Command Unified Life Cycle Engineering (ULCE) Project Forecast II Initiative.

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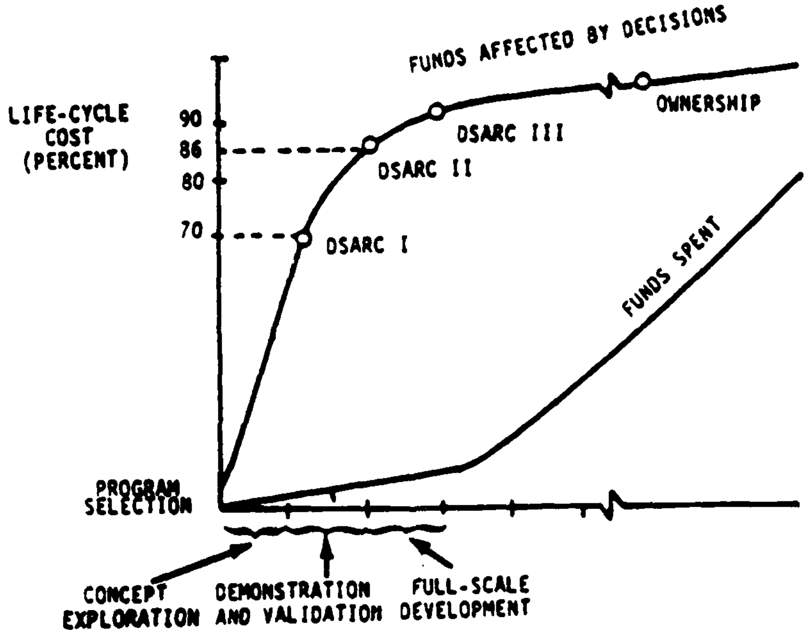
I. INTRODUCTION

Background

Designing a modern weapon system is a complex and very time-consuming process. Very little of the actual design process is automated. The designer must consider performance, cost, schedule, reliability, and maintainability requirements co-equally when creating a design. Reliability and maintainability (R&M) requirements have only recently been elevated to this level of importance by the USAF R&M 2000 Action Plan (USAF, 1985). Although expenditures are at a relatively low level early in a weapon system program, Figure 1 shows that decisions made early in a program determine most of the life-cycle cost of that program.



SOURCE: DEFENSE SYSTEMS MANAGEMENT COLLEGE

Figure 1. Defense Systems Acquisition Review Council (DSARC) Milestones and Impact on Life-Cycle Cost (LCC).

Decisions affecting 70% of the life-cycle cost are made by the end of concept exploration, and 85% of the life-cycle cost is actually determined before full-scale engineering development begins. The earlier that R&M requirements on a program are established, the greater the impact these requirements can have on program planning and ultimately on the life-cycle cost of the weapon system. Clearly, the importance of analysis during the design phase cannot be over-emphasized.

Once a conceptual design exists, it must be evaluated to assess how well it satisfies the design requirements. However, current techniques to analyze a conceptual design for R&M considerations are inadequate. Reliability is fairly well understood, and techniques exist to predict system reliabilities, but linking these to some measure of war-fighting capability is difficult. The existing measures of maintainability are not well understood, and very few techniques exist to analyze the maintainability of a conceptual design.

In anticipation of a replacement gunship development program, the Directorate of Mission Analysis of the Aeronautical Systems Division (ASD/XRM) asked the Logistics and Human Factors Division of the Air Force Human Resources Laboratory (AFHRL/LR) to perform logistics and human factors analyses on the design of a future gunship. The Laboratory recognized this as an opportunity to develop and demonstrate the feasibility of an Air Force in-house capability to respond quickly to requests for evaluations of logistics and human factors impacts of alternative weapon system configurations in the conceptual design phase.

This paper is one of six reports resulting from this research and development (R&D) effort. It documents a methodology for performing logistics analysis of a weapon system during the conceptual design phase. Companion reports which document the results of this R&D effort are AFHRL-TR-86-21 (Dunleavy, Stephenson, & Ness, 1986) and AFHRL-TR-86-58 (King & Weaver, 1987).

Scope

The primary purpose of this R&D effort was to develop and demonstrate the capability to respond quickly to requests for evaluations of the logistics impacts of alternative weapon system configurations while still in the conceptual design phase. A logical extension of this capability is to document the methodology used, in anticipation of other similar efforts. This paper documents a generalized version of one methodology used in this effort, with the hope that it will stimulate other applications.

II. PROBLEM DEFINITION

Defining the problem is the first step in almost all methodology development, and ours followed this pattern. Problem definition is essentially focusing on all that needs to be addressed to properly structure the research question or questions. This involves assembling a group of personnel to understand the problem, determine the objective, and define the research to be performed. The requirement to understand the problem is absolute, and every member of the team must know why the research is being performed. The responsibility of the team, and especially the analyst, is to discover the real problem, not simply a perceived problem or need which may be only a symptom of the underlying cause. Once this has been accomplished, the objective can be defined and the appropriate research questions formulated.

The first step in defining the problem is assembling the research team. The use of a multi-disciplinary team is essential because of the inherent nature of logistics analysis. All relevant disciplines should be represented. In the referenced logistics research effort, the team consisted of a logistician, a Logistics Composite Model (LCOM) programmer, an operations research analyst from the AFHRL, and six contractor personnel including analysts, reliability engineers, and a design engineer. The proper number and mix of persons are unique to each project, but it is essential to obtain as many different perspectives as possible when defining the problem and scoping the research.

An additional crucial step at this point is inclusion of target system operators or, if a new system, those of a comparable system. What is required is the benefit of the users' experience and perspective. This will help prevent the research team from ignoring operational realities which could detract from or, in the worst case, invalidate the results of the effort. It is also important that the user both understand and feel included in the effort. Enthusiastic support from the using agency is invaluable. It can facilitate each step in the process from data acquisition to dissemination and implementation of the results.

The ability to visit an operational user site is extremely valuable. A great deal can be learned about a system by operating and/or seeing a system in operation. This allows the analysis team to receive the expert opinions of users and establish contacts for scenario development and data collection. When used in conjunction with other methods, site visits can greatly improve the team's understanding of the problem. Briefings from operational personnel may be substituted but do not convey the "feel" of the real world.

Once the problem has been determined, the team should focus on defining the objective. The objective must be considered along with certain real-world constraints in mind. These constraints can be considered as falling into one of two categories: management or technical. The most obvious management-type constraints are the resources available to perform the research. This includes the funding, personnel, facilities, and time available to the project leader. These are the types of management issues which are addressed in all well-planned technical efforts. In quick-reaction, short-notice efforts, such as the one reported here, where a team of contractor and Government personnel are involved, it is necessary to have well-planned and coordinated timelines to ensure that all contractual obligations are known and that technical efforts are not impeded.

Technical constraints are those which directly relate to the scope of the technical effort. Examples include the results required for different users, the types of resources needed, and the numbers of scenarios and aircraft to be considered. An initial set of problem ground rules should be developed based on these technical constraints. These ground rules should include a further definition of terms and initial boundaries on the scope of the technical effort. They will provide a baseline from which the research effort can proceed and should narrow the problem area to be addressed, along with the corresponding objective, to one manageable within the existing resource and time constraints.

The final step in delineating the scope of the problem is defining the research to be performed. The scope of the effort should be embodied in the problem ground rules. The team should know who is responsible for each portion of the effort. The required results should be defined and the objective determined. The resulting objective (or each of multiple objectives) should be a concise statement of what outcome is desired from the research effort. Unless the analytical technique to be used has been predetermined, the specific approach and the form of the results will not be known at this point. The paucity of rigid analytical techniques in the logistics analysis arena will tend to force one to remain flexible about defining the actual methodology to be employed. The objective(s), however, should define the analytic techniques appropriate to achieve the desired results.

III. SCENARIO DEVELOPMENT

Scenario development is the process of defining the world in which the analysis will take place. It translates the scope of the effort to operational reality. This world has two descriptive parameters -- a level of reality and a level of abstraction. The level of reality ranges from what we consider to be the "real" world to the "hypothetical" case. The level of abstraction ranges from a simple, abstract representation to a complex, detailed representation. There is an interrelationship between these two parameters. Certain combinations may not be practical to attempt to analyze. For example, if one assumes a hypothetical scenario about which no reasonable extrapolation from a known scenario can be made, it may be not only difficult but useless to define the scenario down to the smallest detail.

The degree to which the scenario is defined is related to two main factors: the desired results and the analysis methodology. Generally, the more detailed the results are required to be, the more detailed the scenario must be. For example, maintenance manpower requirements can be specified as either a total number of personnel required to support a deployment or alternatively, as the required number of personnel by Air Force Specialty Codes (AFSCs) for each work shift. Intuitively, the number of personnel by shift would require a more detailed scenario.

Analysis methodology and level of scenario detail are also interrelated in that normally, the level of abstraction is, in some sense, a determinant of the analysis technique to be used. In actuality, it deletes certain techniques from consideration. For example, mathematical modeling is not normally used to represent a complex, detailed, stochastic process. However, if the analysis methodology has been predetermined, as in the referenced LCOM analysis, the model to be used defines the degree of scenario definition.

An important step in this phase is determining the number of scenarios which will be developed. More than one scenario may be necessary, even with a single objective. Multiple customers or multiple objectives may require more than a single scenario. An analysis using more than one methodology might also require more than one scenario. In our analysis, two scenarios were developed in order to provide some degree of robustness.

Scenario development is an iterative process beginning with the technical constraints developed while defining the problem. Examples include required results, the type of resources needed, and numbers of scenarios and aircraft to be considered. These requirements and constraints are refined to create a scenario. Operational constraints and characteristics such as the degree of weapon system definition, rules of engagement, expected threats and enemy actions, and the influence of regulations must also be included. Operational constraints, individually, define to a very large extent the level of scenario abstraction. Upon completion of this synthesis, the scenario will have been sufficiently defined to properly address the research question. As the research effort progresses, the degree of scenario definition may change. For example, certain data may not be obtainable or an intended analysis technique may not be truly appropriate, forcing changes which cause the scenario to be redefined.

The complexity and depth of the scenario definition must be fully understood by each member of the team. By the end of this step, the scenario should be fully defined and documented as part of the problem ground rules. An example set of problem ground rules can be found in Appendix A. These provided a focus for our team members to perform their specific functions.

IV. DATA ACQUISITION

Data acquisition is the next step of this methodology. Clearly, data requirements must first be identified before attempting to collect data, and those requirements must be directly related to study objectives. This is the cardinal rule of data acquisition. In the referenced effort, use of the LCOM model had been predetermined; thus, data requirements were known and documented. Normally, however, an intermediate step--determining analysis methodology--must be performed. Once the analysis methodology has been determined, the data requirements for that particular analytical technique may also be determined.

Data acquisition should be viewed conceptually as a process involving five steps. The first step is identification of the data. This task is the most important because it is the only input point in the process. All possible data sources, such as existing data bases and publications, must be identified. Knowledge of the source of data in existing data bases is imperative since multiple data bases may each contain different representations of the same data from some common data collection system. If the required data cannot be identified as existing in a usable form, then field data collection may be required. If this is not feasible, then the data requirements cannot be met and the selected analysis technique cannot be used; if this is the case, a new analysis technique must be specified and new data requirements determined.

The second step is to acquire the data. Although some data may come from existing data bases and small amounts of data may even be obtained over the telephone, data collection often requires site visits for field data collection. This generally involves observing and recording the parameters of a process or system in operation. This may be either a normal operation or an experiment which has been constructed specifically for the data collection effort. If field experimentation is necessary, an analyst must help design the experiment to avoid biases in the data caused by the experiment itself.

The third step is to filter and format the data. Filtering is necessary for three reasons. The first is to verify that the data are really what they are supposed to be. The second is to make a thorough and conscientious attempt to understand the validity of the data. There is no exact answer on how "valid" the data must be. The validity of the data primarily affects the results of the analysis and must be accounted for during interpretation. The third is to confirm that the required data have been obtained. This can be accomplished by creating a correlation matrix of data requirements and available data. The data must then be put into a usable form or new data bases created.

The fourth step is to document the data to the fullest extent possible, including source, original format, and any transformations performed during the formatting step. This step must be accomplished. Credible research must be repeatable. This requires the data to be fully understandable by persons not associated with the original research.

The last step in the data acquisition process is the feedback loop. This link back to the data identification step completes the process. Several iterations of these steps may occur before all data requirements have been met. Each iteration updates and refines the data. Once all requirements have been met and the data are fully documented, data acquisition is complete.

Several issues must be considered during the data acquisition phase. The first is possible data sources, which can generally be categorized as Government or contractor sources. The Government has many historical data bases. For example, in this reported analysis effort, certain data were obtained as a result of Air Force Maintenance Management Policy (AFR 66-1). These included historical failure and maintainability data. Other types of data must be obtained at the unit or field level. The minimum essential equipment list for a fully mission capable aircraft is one example of this type of data. Possible data sources include maintenance digests, technical orders, field reports, and personnel interviews. Other data may be more appropriately found at higher headquarters or research laboratories. One example of such data are realistic estimates of the types of aircraft subsystems which should be included in a new aircraft. Possible sources include technical reports, research findings, acquisition documents (e.g., Statements of Operational Need), and personnel interviews.

Contractor-furnished data can also be very useful. However, normally a contract with the particular vendor is required in order to gain access to the desired data. Assuming that a contract mechanism for obtaining the data exists, the data may be treated as any other. The prime aircraft manufacturers usually have extensive data bases on their aircraft at the weapon system level. Data on airframe modifications, for example, are usually readily obtainable from the prime contractor. The subcontractors are usually the experts on the subsystems which they build. Engineering reliability estimates for a new sensor system are more appropriately the domain of the responsible subcontractor. In our effort, for example, the Lockheed Corporation provided data on the stretched model C-130 aircraft and the Texas Instruments Company provided engineering reliability estimates for a new Forward Looking Infra Red (FLIR) system.

Until now, it has been assumed that the system about which data are being collected does in fact exist. For new weapon systems, however, all or portions of the system usually do not exist. For new systems for which no historical data are available, one source of data is comparability analysis. This is the process by which data from a "comparable" system are transformed into data which reasonably represent the new system. This technique is documented in the referenced scientific literature and will not be expounded upon here.

The availability of data is an issue which must be addressed. Not all data may be accessible in a timely manner or available at all. If the data are not complete, procedures must be developed for handling missing data. Security classification of the data is another issue. Scenario data, system data, and any combinations which may reveal operational capabilities may be classified. Working with classified data has many ramifications which must be well thought out.

V. ANALYSIS

Modeling

Modeling is performed to gather information on systems or processes which are outside the realm of historical data. Modeling can also be used for performing sensitivity analysis, which is necessary for interpreting the results. The simulation model we used in this analysis effort was LCOM. LCOM is a stochastic model, which means that events will occur in the model according to probability distributions. This is in contrast to a deterministic model, in which events occur at a specific rate. The model should not be confused with the underlying process which it represents, however. The process which is being simulated may be either a stochastic or deterministic process and so can the model which represents it. A stochastic model is usually the more detailed of the two because it requires a more exact knowledge of the actual probability distribution of the underlying process. The demand for aircraft spare parts, and its impact on the supply system, is generally considered to be an example of a stochastic process. LCOM simulates this process with a stochastic treatment. The repair capability of an intermediate maintenance facility is another process which is treated stochastically by LCOM.

One consequence of using any stochastic model is that multiple runs are required to increase confidence in the output. This is because the outputs are statistical observations. Most of these observations will be fairly "likely," but extremes may occur due to highly "unlikely" events. Deterministic models require only one run for each set of conditions. This observation is made to provide an awareness of the magnitude of computing resources which are required for a thorough evaluation of alternative designs, along with sensitivity analyses for interpreting the results.

Interpreting the Results

Model results may or may not equate to the desired measure of effectiveness (MOE). In this case, either some transformation must be made or alternative MOEs must be explored. Three example MOEs for LCOM are flying hours, sorties, and available ready aircraft. No matter what form the results are in, however, they must be interpreted.

The results of any simulation model cannot be taken at face value. Sensitivity analyses should be performed to determine how sensitive the results are to changes in the input conditions. The critical factor, however, is how the results contribute to solving the problem being addressed. Large-scale simulation models are usually general-purpose models. These types of models are tailored by proper manipulation of the input conditions instead of by modifying the model itself. The meaning of the results will depend primarily on the nature of the input data and the problem which is being solved. For example, in the referenced LCOM analysis, maintainability data on the new gunship could not be obtained. Maintainability data for the current gunship were used instead. This changed the intended analysis from a quantification of absolute maintenance manpower requirements to a quantification of the impact of changes in hardware reliability on maintenance manpower requirements, and totally changed the interpretation of the results.

An analyst must be heavily involved both in performing the modeling and in interpreting the results. These two steps are crucial to the entire analysis and must be performed in a systematic and valid manner in order for the entire effort to be credible.

VI. SUMMARY

This paper documents a methodology for performing logistics analysis during weapon system design. It is a generalization of specific analytical techniques which were used in the referenced R&D effort.

The major steps are: defining the problem, developing the scenario, acquiring the data, performing the modeling, and interpreting the results. This systems analysis approach is punctuated with specific examples from the analyses which were performed. An outline of methodological considerations (Appendix B) has been developed for use by anyone contemplating performing logistics analysis. It is hoped that further use will refine and extend this methodology to a point where logistics analyses can be routinely performed during conceptual weapon system design.

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APPENDIX A: PROBLEM GROUND RULES

The following assumptions and ground rules were used in conducting the subject study.

The logistics requirements to support deployment/employment of a representative high-technology gunship will be computed for each of two hypothetical scenarios. These requirements are, for the purpose of the present study, limited to spares, support equipment (SE), personnel for direct support and operation of the aircraft, fuel, ammunition, chaff, and flares. Other logistics resources/issues will be addressed only as time and budget permit.

Air Vehicle

The air vehicle for this study will be a C-130H-30 aircraft, modified as necessary to accept a sophisticated sensor/weapons/operator package. Aircraft modifications will be identified in conjunction with the mission package and will include such changes as hydraulic and electrical power system augmentation. The mission package will reflect technology available in the mid-1980's and will be based on Lockheed's proposed Special Operations Forces (SOF) improvement package for existing AC-130H gunships.

Operations from a Main Operating Base (MOB)

In this hypothetical scenario, 10 gunships will be deployed to, and employed from, a Main Operating Base (MOB). The MOB will have substantial maintenance, supply and facility resources, but these will not be totally adequate to support the gunship operation.

The MOB will be 400 nautical miles (nm) from the operating area. All 10 aircraft will be launched in relatively rapid succession. Five aircraft will fly to the operating area, remain on station for approximately 6 hours, then return to base, for a total sortie duration of 10 hours. These aircraft will require inflight refueling in order to complete their mission. The other five aircraft will fly to the operating area, remain on station for only 3 hours, then return to base, for a total sortie duration of approximately 7 hours. One aircraft will be lost on each of the 10th and 20th days.

With the exception of fuel and ammunition requirements, estimation of the logistics resources required to support the gunships will be based on each aircraft flying 10 hours per day for 30 days, even though the preceding assumptions on sortie duration and on aircraft attrition will result in fewer flight hours over the total scenario. In addition, it is further assumed that each gunship will expend its full load of ammunition on each sortie flown.

Logistics resources to be deployed to the MOB are:

1. Organizational-level maintenance personnel for both aircraft and mission equipment.

2. Organizational-level support equipment for mission equipment.

3. Intermediate-level maintenance personnel for mission equipment.

4. Intermediate-level support equipment peculiar to mission equipment.

5. Spare engines (Quick Engine Change (QEC) Kits with propellers) to be accompanied by gunship-dedicated engine change personnel.

6. Support equipment for engine change.

7. Spare Line Replaceable Units (LRUs).

8. Spare Shop Replaceable Units (SRUs).

9. Ammunition, chaff, and flares.

MOB resources which, for the present study, will not be addressed include:

1. Organizational-level support equipment for the aircraft, except that peculiar to engine change.

2. Intermediate-level maintenance personnel for aircraft components or the air vehicle as a whole.

3. Consumables other than ammunition, chaff, and flares.

4. Facilities, equipment, or personnel for base operations (food, housing, security, air traffic control, etc.).

Operations from a Forward Operating Location (FOL)

In this hypothetical scenario, 10 gunships will be deployed to, and employed from, a Forward Operating Location (FOL). The FOL will have only limited maintenance, supply, and facility resources for a 10-gunship, 30-day operation. The FOL will be 200nm from the operating area, and will receive logistics support from an MOB 500nm further removed from the operating area (i.e., MOB to FOL = 500nm; MOB to operating area = 700nm). All 10 aircraft will be launched in relatively rapid succession. Five of these 10 aircraft will complete a 10-hour sortie which will include approximately 8 hours on-station. These aircraft will require inflight refueling to complete their mission. The other five aircraft will take off with sufficient fuel for a 3-hour on-station mission without inflight refueling, at which time they will return to base having flown approximately 5 hours. One aircraft will be lost on each of the 10th and 20th days.

With the exception of fuel and ammunition requirements, estimation of the logistics resources required to support the gunships will be based on each aircraft flying 10 hours per day for 30 days, even though the preceding assumptions on sortie duration and aircraft attrition will result in fewer flight hours over the total scenario. In addition, it is further assumed that each gunship will expend its full load of ammunition on each sortie flown.

Resupply of consumables from the MOB to the FOL (i.e., fuel and ammunition) will be on a daily cycle. Up to three engine/propeller changes will be handled as dispatch maintenance from the MOB; that is, the spare engines (QEC kits and propellers) will be dispatched from the MOB, but the engine change crew/personnel will be at the FOL. Logistics resources to be deployed to the FOL are:

1. Organizational-level maintenance personnel for both aircraft and mission equipment.

2. Organizational-level support equipment for both the aircraft and mission equipment.

3. Spare LRUs (including spare engines - QEC kits with propellers).

4. Ammunition, chaff, and flares.

Logistics resources to be deployed to the MOB that will support the FOL are:

1. Intermediate-level maintenance personnel for mission equipment.

2. Intermediate-level support equipment for mission equipment.

3. Spare engines (QEC kits with propellers).

4. Support Equipment for engine change.

5. Spare SRUs.

FOL and MOB resources which, for the present study, will not be addressed include:

1. Intermediate-level maintenance personnel for aircraft components or the air vehicle as a whole.

2. Facilities, equipment, or personnel for base operations (food, housing, security, air traffic control, etc.).

APPENDIX B: METHODOLOGICAL CONSIDERATIONS

Problem Scoping (focus on all that needs to be done/addressed/etc. to properly structure research questions):

1. use of multidisciplinary team.

2. inclusion of users.

3. site visitations and/or briefs.

4. definition of objective.

5. development of problem ground rules.

6. definition of research.

Scenario Development (amount of reality versus abstraction as a determinant of modeling approach):

1. specific versus abstract or real world versus hypothetical.

2. degree (complexity and depth) of scenario definition.

3. iterative process.

4. operating constraints.

5. refinement of problem ground rules.

Data Acquisition (should use a "total system orientation"):

1. treatment as a process.

    a. identification.

    b. retrieval.

    c. filter/format.

    d. documentation.

    e. feedback/iteration.

2. considerations.

    a. Government sources.

        - unit/field.

        - other/MAJCOM/Air Staff, etc.

b. contractor sources.

- prime/airframe.
- systems/subsystems.

c. new equipment (comparability analysis).

d. availability.

e. ease of access.

f. handling missing data.

g. data classification.

- access to classified data.
- use of classified data.

3. Analysis

a. modeling (necessity for parametric/sensitivity analysis).

- deterministic versus stochastic treatment.
- alternative measures of effectiveness (MOEs).
- magnitude of effort.

b. interpreting the results.

- sensitivity analysis.
- application to the problem.

END
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